Sensing the Coastal Zones Remotely

Robin Vaughan

A.P.E.M.E.
University of Dundee
Dundee DD1 4HN, U.K.

ABSTRACT

A brief survey is presented of some of the instruments used for remote sensing which have been developed over the past few years which are particularly relevant to the study of coastal zones. Special mention is made of the new generation of imaging spectrometers, and their use in the monitoring of coastal zones is compared with other available systems, both satellite-borne and airborne. It is suggested that, because of the complexity of the coastal zone environment and the range of scales involved, no one set of data can adequately provide the information required for monitoring and that a synergism of data sets of different types and scales should be most useful in this context.

1. INTRODUCTION

Over half the world's population lives close to that narrow interface where the land meets the sea. Europe itself has about 132,000 km of coastline and over 30% of Europe's beaches are subject to erosion. It is not surprising that a great deal of effort is now being focussed on the management of the coastal zones, and their monitoring is therefore of prime interest to a wide range of agencies of different types. Indeed, the European Space Agency (ESA), at its recent User Consultation Meeting in Noordwijk, identified the coastal regions of Europe as priority areas in its future programmes. Remote sensing in its many forms lends itself well to such monitoring applications, but many of the current systems were originally designed for other uses and, as such, their specifications may not be ideal for these applications. A number of new instruments are being developed which lend themselves much more to this type of work, and indeed others are being designed with such purposes in mind. This paper is not intended to provide a detailed review of particular instruments, but rather to present a brief overview of the present situation and of future possibilities, with the emphasis predominantly on the European dimension, in view of the Workshop at which it was presented.

The coastal zone is the interface between the land and the ocean, and as such it is particularly susceptible to natural and anthropogenic changes. Whereas many of the processes which take place in these regions are local, and hence need to be studied locally, their impact may be felt regionally, or even globally, and so any findings of local studies may need to be extrapolated. Possible fields of study include coastal and dune erosion, flooding, beach processes and shallow water bottom changes, river discharge, sedimentation, sea-level changes, anthropogenic impacts on estuaries and coasts, vegetation changes, biological balance feedback and controls on environmental change and various forms of natural and man-made pollution. The importance of understanding the land/ocean interaction, such as how changes on land may influence the biochemical and biophysical processes of the coastal seas, and vice versa, is fundamental to an assessment of the global implications of local changes in coastal seas.

In spite of the huge diversity of monitoring needs in coastal regions, it is surprising that such little attention has been directed towards these areas in the past. This may be due to the fact that the diversity of spatial, spectral and temporal resolution for the different types of monitoring needs is so great that it is difficult to produce a specific "coastal zone monitoring" sensor. Yet developments in recent years have shown that interest in monitoring this area will increase dramatically as the potential of remote sensing in this complex and vitally important environment is realised. These are highly dynamic regions, with a very wide range of spatial variability The spatial and temporal resolutions of satellite data are usually too poor to study the subtleties of many coastal processes, whereas such data are invaluable for providing the context into which finer detail can be fitted and for enabling extrapolations to be made.

Conversely, aircraft-flown data would seem to have the temporal and spatial flexibility desired for this type of work, but very often over only restricted parts of the region of interest.

In addition, the complexity of the environment means that different types of information require data in different parts of the electromagnetic spectrum. In the waters, high spectral resolution in the visible may be necessary for looking at phytoplankton, suspended sediment, bottom reflectance, effluent or ocean colour. Infrared wavelengths are needed for land/water discrimination, thermal infrared for monitoring outfalls and mixing processes and microwaves for roughness, slope, currents, ship movements and oil slick detection. Combinations of all these wavelengths may be needed in the "dry" part of the coastal area as well for monitoring vegetation, dunes, human developments, natural resource exploitation, effects of tourism and other natural and anthropogenic changes. No single instrument or platform can hope to provide data for more than a very restricted range of applications, yet many phenomena are highly interdependent. Hence no aspect environmental monitoring can benefit quite as much from a synergistic approach as the study of coastal zones.

There are some applications in which remote sensing is becoming almost operational in use, for example for oil slick detection, ship monitoring, mapping and pollution control, and great efforts are now being made to make some of these applications fully operational. Not many of these activities have yet been reported in the mainstream remote sensing literature, and one has to go to specialist journals or conference proceedings to realise the extent to which these ideas are being developed. An example of this is the considerable progress that is taking place in the development of imaging spectrometers of various types and with increasingly impressive specifications. This work, though, is still in its infancy and many of the applications reported are as test beds for particular instruments. At the recent conference on airborne remote sensing held in Strasbourg (1994), over twenty papers reported developments in such instrumentation and several applications to coastal work were described.

Of considerable current concern is that, over the next few years, more and more data, of increasing complexity, will become available, but will the necessary analytical tools be developed in order to maximise the use of the data? It is not *data* that the end-user requires but information. Some types of simple *information* can be extracted quite easily, say, from visual inspection of photographs or colour composite images, but more subtle information, particularly of a quantitative nature, may require ingenuity and considerable scientific skills for its extraction. Some movement is taking place, some reported at this Workshop, towards the use of GIS incorporating remotely sensed data to form coastal zone management systems. This is, however, but the first step. The simple overlaying of imagery may well be useful, but the integration and analysis of multi-datasets, as is implied in the synergistic approach, should open up vast new areas of exploitation.

2. SATELLITE SYSTEMS

The low spatial, spectral or temporal resolutions of the majority of satellite data limits their use in most applications in these highly dynamic and complex regions. Even so, a considerable amount of useful work has been done and indeed is still being done. At this Workshop, there are reports of AVHRR data being used in France, the Ukraine and Sweden, SPOT HRV data being used in Poland and Spain, TM in Italy, Turkey and Argentina and several reports of the use of ERS SAR data. The JRC at Ispra has ongoing programmes (OCEAN and OCTOPUS) involving the mapping of coastal waters using historic CZCS data and the integration of remote observations into coastal zone management schemes. Other useful work has been done in mapping, shallow water bathymetry, flow patterns and vegetation studies, particularly where changes may be taking place which may indicate anthropogenic pollution. One major advantage of satellite data is the availability of historical data. The Landsat series has been operating continually since 1972 providing an archive of reproducible imagery which can be used as baseline information on coastal environments or enable rates of change to be quantified.

Two basic problems are inherent in using satellite data. The first is the effect of the atmosphere, exacerbated by the high orbital altitudes. Even cloudless skies scatter most of the radiation from the detected signal (typically 60% of the reflected visible and 75% of the emitted thermal signal) particularly at the blue end of the spectrum where penetration of water, permitting bathymetry for example, is greatest. Corrections for atmospheric effects, particularly for quantitative or comparative work, is therefore essential. The second restriction is that satellite sensors are usually calibrated for land features, providing much lower sensitivity for the less reflective aquatic regions. Added to the requirement for cloud-free conditions (except for SAR, of course) and the low temporal resolution of most satellites, these considerations severely limit the application of this sort of data.

Table 1 - Relevant satellite systems

Instrument	Platform	No. of channels	waveband	Spatial resolution	Swathe	Temporal resolution
AVHRR	NOAA	5	0.58 - 12.4	1.1km	3000km	12 hrs*
ATSR	ERS	7	0.65 - 12	1km (.5km vis)	500km	3 - 35 days
CZCS	NIMBUS #	6	0.44 - 11.5	825m	1566km	6 days
HRV	SPOT	4	500-890nm + pan	20m (10m pan)	117km	27 days**
MERIS	ENVISAT $	15	0.4 - 1.05	300m or 1200m	1500km	
MODIS	EOS $	36	0.4 - 14.4	250m and 1000m	2300km	
MVIRI	Meteosat	3	0.5 - 12.5	2.5km and 5km	full earth	30 min
Ocean Color (SeaWiFS II)	EOS COLOR $	8	402 - 885	1.1 - 4.5km	2800km	
OCTS	ADEOS $	12	0.4 - 12.5	700m	1400km	41 days
SeaWiFS	SeaStar $	8	402 - 885nm	1.1 - 4.4km	1500 - 2800km	16 days
TM	Landsat	7	0.45 - 12.5	30m and 120m	185km	16 days

* - Two operational at any one time providing 6hr overhead passes, but data available from several other non-overhead passes each day
** - steerable +/- 27 deg from nadir giving increased temporal resolution
# - died 1986
$ - planned

Table 1 lists some of the more relevant satellite systems that are now available (with the exception of the Coastal Zone Colour Scanner, CZCS, which operated from 1978 to 1986 and, up till now, has been the only instrument specifically designed for ocean colour work - archived data is still available and is well-used) or are planned to fly on future missions. With the environment being high on the scientific and political agenda at present, a great many missions are intended to operate over the next ten or fifteen years, some of which will carry enhanced instruments such as MERIS (MEdium Resolution Imaging Spectrometer) on the first European Polar Platform (ENVISAT), MODIS on the first US Polar Platform,and the PRISM concept of a high resolution imager being studied by the European Space Agency. This latter has chatacteristics similar to those of NASA's HIRIS instrument which has now been dropped from the US Polar Platform programme but which may find a place on another platform. Some of these instruments are at present being tested in airborne missions and more will be said about imaging spectrometers in a later section. It must be remembered, though, that high spectral resolution is often achieved, on satellite platforms at least, at the expense of lower spatial resolution, and, of course, Newton's laws will always restrict the temporal resolution for orbital platforms. An up-to-date compilation of current and future European satellites and instruments has recently been produced by Scot Conseil and Smith System Engineering Ltd (1994). This is the final report of a study for the European Commission entitled «Use of Satellite Data for Environmental Purposes in Europe». For a good survey of the worldwide situation, the new edition of Kramer's book (1994) is highly recommended.

The reason for presenting table 1, which contains very condensed information of little practical use, is really to illustrate the range of specifications available. The first thing to note is the restricted number of spectral channels available on present instruments. This is a basic limitation of any scanning instrument, but the advent of CCD arrays has enabled great advances to be taken and has made hyperspectral imaging feasible. The second point is that there is usually a trade-off between spatial and temporal resolution (and also, to some extent, radiometric resolution) because of technical reasons such as limits on data transmission rates. Again, technological developments are expected to enable even that restriction to be relaxed in future systems.

3. AIRCRAFT SYSTEMS

For many applications, particularly in coastal zones, aircraft are still popular and reliable platforms. Any instrument flown on a satellite can, in principle, be flown on aircraft, and indeed most satellite systems were tested out on aircraft. But the converse is not necessarily true, and some aircraft systems (for example cameras and at present hyperspectral imagers) are rarely flown on satellites for technological reasons.

3.1 Cameras

Aerial photography has probably been the most widely used form of remote sensing of coastal regions and, in its classical form, still provides much useful mesoscale regional information. Recent developments in high resolution digitising instruments has made such data even more compatible with other datasets as well as enabling it to be used as input to an image processing system or a GIS.

Some work has been carried out using small format (35mm) photography (Roberts 1992). He used infrared Aerochrome and colour diapositive film in two Nikon F250 reconnaissance cameras flown on a light survey aircraft. The digitising of such colour films using filters makes multispectral image processing a possibility. A great deal of historical conventional photographic material exists which is very useful for monitoring changes, and the commissioning of new photographic surveys, both panchromatic and colour, still remains a cost effective option for many purposes

3.2 Video recorders

Video recording from aircraft is also quite a widely used technique. The radiometric resolution of video data can be much greater than that of photographic film due to the steepness of its characteristic curve, although its spatial resolution is lower. A problem arises from its extreme sensitivity to changes in contrast resulting in saturation (flaring), when, for example, the traverse crosses the boundary between land and water. There are a number of other practical advantages of video, such as its low cost, no requirement for chemical processing, the electronic format which allows computer processing and high data storage (up to 40,000 Mbyte for typical 90 minute reel). Other advantages include the ability to change exposure settings in flight and to view the data almost immediately. This technique is particularly useful for assisting in the collection of ground truth data in near real-time. Bakker, at this Workshop, describes the use of such a technique for producing an inventory of coastal dune areas, and Roberts (1992) reports the use of a multispectral video system (MSV) comprising three Sony CCD cameras fitted with with green, red and near IR bandpass filters. The automatic gain control had to be disabled so that quantitative comparisons could be made, and vignetting corrections were necessary to compensate for intensity variations across the image. From 1200m, the spatial resolution was 2.5m, although with a speed of 120 knots, a shutter speed of 1/60 sec produced a certain amount of blurring due to the 1 m movement of the ground pixel during exposure. Use has been made of this instrument, particularly in Canada, for monitoring salmon spawning, river flooding, suspended sediment concentrations and stem density of eel-grass in intertidal zones.

3.3 Scanner systems

A number of scanner systems have been flown on aircraft and, because of the higher spatial resolution available than when flown on satellites, these are particularly suited to work in the coastal regions. They usually have more spectral channels than their satellite-borne counterparts, and the temporal flexibility also is an advantage. Perhaps the most widely used is the Daedalus AADS 12689, commonly called the Airborne Thematic Mapper (ATM) because of the coincidence of seven of its eleven channels with those on Landsat TM. This instrument requires a larger aircraft than does MSV, and therefore provides much more limited access, and is usually flown at a greater height. A lot of work has been carried out using the ATM. For example in the UK the Natural Environment Research Council (NERC) has been flying such an instrument for many years in a Piper Chieftan aircraft and many researchers and organisations have made use of the data. Other scanners, for example thermal line scanners, have also proved to be of great use in many situations requiring good spatial resolution and flexibility of timing of operation.

3.4 Imaging spectrometers

Modern technological developments involving the use, in particular, of charge coupled device (CCD) arrays has brought about a revolution in the field of hyperspectral imaging. Many such devices are being developed (see **table 2**), with very impressive specifications. In most cases, some form of dispersing element is used to spread the spectral components of the image across the CCD providing two of the dimensions of the hyperspectral cube, the third being provided by the forward motion of the platform. Various mechanisms for sampling this three-dimensional data enable images with high spectral or spa-

Table 2 - Specifications of some imaging spectrometers

Name	Spectral bands	Spectral range (nm)	Bandwidth (nm)	Quantisation (bits)	FOV (degrees)	IFOV (mrad)
AIS	128	800-2400	10			
ASAS	30	465-871	15		25	5
AVIRIS	224	400-2450	9.4-16	10	30	1
CAESAR	12	400-1100	20-220	12	25	.25
CASI	15/288	430-950	2.9	12	35	2.4
DAIS-7915	80	400-12300	10-2000	15	39	3.3
FLI/PMI	8	430-805	2.5	12	72	1.3
GERIS	64	400-2500	25-120	16	90	2.5
HIRIS	192	400-2450	10	12	2	30m
ISM	128	760-3160	12.5-24			
MERIS	15	400-1050	1.25	12	82	0.32
MIVIS	102-128	433-12700	8-500	12	70	2
MODIS	64	420-1420	10	10-12	90	1.4
ROSIS	30-80	430-850	4/12	12	16	0.55
SFSI	122	1200-2400	10	8	10	0.33
SMIFTS	35/75	1000-5300	50/100	12	6	0.6
VIFIS	576	420-1060	10-14	8/12	48	0.3
VTVHSI	1024	300-1100	0.6		35	0.6
WIS	64	400-1000	1.2%			

tial resolution to be reconstructed. The choice of mode or number of wavebands actually recorded needs to be predetermined for many of the instruments shown in table 2. The number of spectral bands quoted in the second column are often the maximum available, but only a proportion of these may be obtainable at any one time, and so it is difficult to attempt to make any form of comparison between systems. For example, the CASI instrument has up to 288 channels at 1.8nm spectral intervals in contiguous bands between 0.4 and 0.9 mm. The exact number of bands, their widths and their location can be programmed in flight and it can work in either spectral or spatial mode, but not both at the same time. Most of the information in this table has been extracted from the review paper by Staenz (1992) and from reports of individual instruments in, for example, the proceedings of the International Airborne Remote Sensing Conference recently held in Strasbourg (1994). The exact specifications of many of these instruments may vary, however, depending on which report you read and at what stage the development programme had reached when the data were published.

Two EUROCOURSES on imaging spectroscopy have been held at the European Joint Research Centre in Ispra. The first in 1989 (Toselli and Bodechtel, 1992) included marine applications of imaging spectrometry, and the second in 1992 (Hill and Megier, 1994) covered the assessment of terrestrial ecosystems. Both these publications provide good, indepth, reports of applications and analytical techniques. Space does not permit a full analysis here of the relative merits of all the instruments mentioned, but the book by Hill and Megier includes a fairly up-to-date survey of imaging spectrometers by Curran (1994), to which the reader is referred for detailed information about the then current situation and the specifications of systems.

Some advanced sensor systems, such as NASA's AVIRIS have become available for international research programmes and ESA, on a European level, under the ERSEC programme, has enabled the development of the DAIS-7915 instrument and initiated an airborne remote sensing campaign in which imaging spectroscopy is intended to play an important part. But a large number of the instruments have been developed by individual laboratories with specific applications in mind and are still being tested out and modified. It can be seen from table 2 that the number of spectral bands available range from 8 to 1024, with bandwidths from a few to thousands of nm and extending, in some cases, well into the infrared. The dynamic range is also considerably greater than that on satellite systems in order to accommodate the large changes in signal level with wavelength that are encountered. These variations in general tend to be smoothed out in the broadband detectors. Quantisation varies from 12 bit to 16 bit in order to accommodate these ranges.

One instrument which does not suffer from the disadvantage of programming to particular requirements is the Variable Interference Filter Imaging Spectrometer (VIFIS) developed in the Author's laboratory (Sun and Anderson, 1994). This is an easily-deployable miniature sensor system consisting of three synchronised CCD-imager modules (simple commercially-available video cameras) aligned to a common field of view. Two of these have interference filters cemented across the face of the CCDs, the third is used to provide a panchromatic image enabling bidirectional reflectance to be investigated. The 8mm video recording/monitoring unit is hosted by a a 486 PC which provides real time data processing. Multispectral images and spectral profiles may be reconstructed in real-time using a transputer co-processed video rate pushbroom queue processing algorithm, and complete spectral and spatial information storage and retrieval is incorporated into the system. Unlike a dispersion imaging spectrometer, for which primary imagery formed on a sensor is a dispersed line scene and beyond a human's perceptability if the imagery is directly inspected, the primary imagery that is formed on the sensor remains humanly recognisable except that the spectral component varies across the image. This enables the raw image to be inspected in flight using a simple battery operated camcorder, and any required spatial or spectral image to be reconstructed *afterwards,* thereby obviating the need for pre-programming and enabling much greater flexibility in application.

4. ACTIVE SYSTEMS

Synthetic aperture radar, flown on both satellites and aircraft, has been used extensively for coastal zone work. This can be used for land use studies, bathymetry, monitoring flooding events and coastal defences, mapping, wind and wave monitoring, ship detection etc. An important application is in the field of pollution monitoring and techniques for automatic oil slick detection are being developed (Sloggett 1995). The spatial resolution of ERS-1 SAR (about 30m) may not be suffient for many applications, and, depending on revisit times, there may be problems in separating wind, current and bottom-topography effects in coastal waters. The all-weather capability, however, is unique amongst remote sensing systems. A number of SAR systems flown on aircraft provide the greater spatial and temporal flexibility that is often the requirement in the coastal zones. Some of these systems incorporate an interferometric capability (INSAR) which has the potential to measure small changes in position and topographical information. Real Aperture Radar (RAR or SLAR) has also been used extensively over the years for observing oil slicks and for coastal protection monitoring.

SAR is not the only active system, however. Radar altimeters and scatterometes can give valuable information for use in mapping and sea-state monitoring, although again space-borne systems have relatively poor resolution. There is also some interest in active laser systems, even to the extent of their being carried on future satellite missions. At present the platform is usually a helicopter. Bathymetry measurements have been carried out using two-frequency instruments - pulses of laser light are directed downward (Muirhead and Cracknell, 1986). The red beam is reflected predominantly from the surface and the green beam penetrates the water and is reflected from the water bed. Difference in transit time indicate the extra path travelled through the water. Other laser systems have been designed to measure fluorescence signals from oil films or chlorophyll-a (Seshamani et al 1994) providing much greater discrimination than the use of passive systems. Another type of active system which has great potential in this field of work is side-scan sonar in which bottom topography profiles can be generated and sub-bottom features investigated.

5. CONCLUSIONS

It can be seen that most remote sensing instruments and platforms can find a place in the study of the coastal zones, but that no single instrument is ideal. With the "top down" approach which has driven the design and implementation of satellite systems in the past, only limited input from the user community has been solicited. The same is true to some extent of the larger-scale airborne instruments, and the user has had to make do and adapt. The ingenuity of many users is surprising when it come to finding unexpected uses for data, such as all the non-meteorological applications of AVHRR data. But there is a limited amount of information about the complex coastal zone which can be obtained from the broad-band, low resolution systems available until recently. The advent of imaging spectrometers carried on easily-deployable aircraft means that perhaps now data can be collected specific to the problem in hand. But the solution to the environmental problem requires more than just data, however well-resolved - it needs the integration of many different types of information, both remotely-sensed and other. It would seem that, at long last, the end users are being convinced that remote sensing has a role to play in the study of these uniquely important areas of the coastline. It is now time to move on from research into the real world of operational systems.

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